non-GSO MSS feeder links) could affect implementation of the 28 GHz plan, and the Commission requests comment on what if any contingency plans should be considered.

It is, of course, possible that WRC-95 will not adopt the United States' proposals. Already several Administrations are proposing that only 200 MHz should be allocated to non-GSO MSS feeder links at 20/30 GHz. The failure of the WRC-95 to adopt the Commission's proposed 400 MHz allocation would exacerbate an already difficult coordination/sharing situation between GSO FSS and non-GSO MSS feeder links. For purposes of WRC-95, such a failure would make it all the more imperative not only to exclude RR 2613 from the 200 MHz of feeder link spectrum, but also to protect non-GSO feeder links in that spectrum from GSO FSS VSAT systems. For purposes of this rulemaking, the adoption of only a 200 MHz feeder link allocation at WRC-95 would make it necessary to segment further the 29.1-29.5 GHz band, protecting the GSO MSS feeder links from VSAT networks in the 29.1-29.3 GHz band and permitting greater freedom for GSO/FSS in the 29.3-29.5 GHz band.

II. Licensing Rules for Ka-Band FSS Systems

A. Auctioning Spectrum for International Systems Would Be Against the Public Interest

The NPRM tentatively proposes use of auctions to award both non-geostationary and geostationary FSS licenses in the event of a mutually exclusive situation. Motorola opposes the use of auctions for licensing international (indeed global) satellite systems because of the potentially catastrophic effects of auctions on the goals of the Commission's international communications policies.

Competitive bidding for international satellite systems is clearly inappropriate and contrary to the public interest. The United States' use of auctions to award licenses and/or allocate spectrum for international systems may lead other countries either to follow the U.S. lead or to exact exorbitant license or spectrum fees using the price paid to the United States as a gauge, thereby creating a global patchwork of prohibitively expensive licenses that might be impossible to accumulate. This, in time, could add uncertainty, greater risks, and incalculable costs to the process of constructing and licensing a global system, thereby threatening the ability of any U.S. licensee to develop a global system and depriving the public of the one major benefit of the low-earth-orbit architecture -- the global universal service.[24/] Ultimately the formidable auction costs would have to be passed on to consumers, making the service offerings of these systems considerably less affordable and again compromising the Commission's goals -- particularly the elimination of the distinction between communications have and have-nots.

In addition to raising the cost of a global system to potentially uneconomic heights, the specter of multiple auctions abroad would add considerable uncertainty to the process of valuing the spectrum auctioned within the United States. Without knowing the value of (or the feasibility of obtaining) spectrum rights in other countries, the U.S. industry would be unable to accurately access the value of the spectrum auctioned at home, or, for that matter, to accurately access what its costs would be world-wide. The type and quality of information necessary for bidders to make informed rational decisions and for the bidding process to ensure an efficient allocation of resources would simply be absent. Lack of information would indeed make it very doubtful that auctions "will encourage efficient use of the spectrum" as suggested in the NPRM.[25/]

[24/] In the Matter of Amendment of the Commission's Rules to Establish Rules and Policies Pertaining to a Mobile Satellite Service in the 1610-1626.5 MHz and the 2483.5-2500 MHz Frequency Bands, 9 FCC Rcd. 5936, 5940 (1994) ("Big LEO MSS Licensing Order").

[25/] NPRM ¶ 133.

B. The Commission Should Exhaust Other Methods of Avoiding Potential Exclusivity

Even if the use of auctions were not contrary to the public interest, a Commission decision to adopt competitive bidding at this point would be premature. As the NPRM correctly recognizes, the Communications Act permits auctions only in the case of mutually exclusive applications.[26/] With only one Ka-band NGSO applicant so far, a mutually exclusive situation has of course yet to arise. Sharing between Teledesic and another applicant's system may well be possible.[27/] In any event, if the potential for mutual exclusivity does arise, the statute permits the Commission to use competitive bidding only after attempting to avoid mutual exclusivity by other methods not implicating auctions, including "engineering solutions, negotiation, threshold qualifications, service regulations, and other means in order to avoid mutual exclusivity in application and licensing proceedings. . "[28/] Indeed, as Congress itself has noted, the need to avoid mutual exclusivity by such methods is particularly strong where global satellite systems are concerned.[29/]

The Commission can significantly reduce or altogether avoid the potential for mutually exclusive applications by adopting appropriately stringent technical and financial qualification requirements, which will also help to ensure that speculative,

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26/ 47 U.S.C. § 309(j)(1) (Supp. V 1995), NPRM ¶ 129.

27/ As stated above, the Commission has also raised the possibility of auctions for GSO FSS licenses, recognizing again that its auctioning authority attaches only in mutually exclusive situations. Such a situation is unlikely to arise in this round of Ka-band GSO FSS applications. The geostationary arc in the Ka-band is still almost virgin, and orbital separation is likely to successfully avert any potential for mutual exclusivity. Accordingly, considering auctions for GSO FSS applicants is unnecessary at least at this time.

28/ 47 U.S.C. § 309(j)(6)(E). <u>See also</u> H.R. Rep. 111, 103rd Cong., 1st Sess. 258-59 (1993), <u>reprinted in</u> U.S.C.C.A.N. 378, 585-86; Letter from John D. Dingell, Chairman, House Committee on Energy and Commerce, to James H. Quello (Nov. 15, 1993).

29/ <u>Id.</u>

sham or unqualified applicants do not prevent fully qualified competitors from going forward. Historically, there have never been mutually exclusive satellite applications. The adoption and application of high threshold requirements have effectively limited the number of qualified satellite applicants, thereby avoiding mutual exclusivity.

1. The Commission Should Require Global Service Capability

The Commission should require Ka-band non-geostationary applicants to be capable of providing global service. The public benefits of this requirement have been repeatedly recognized by the Commission and are central to the Administration's goal for a Global Information Infrastructure. Just last year Vice President Gore expressed his vision of a global infrastructure that would "bring all the communities of the world together" through "a planetary information network that transmits messages and images . . . from the largest city to the smallest village on the continent."[30/] The Commission itself recognized the link between global coverage requirements and the GII in its Big LEO MSS Licensing Order when it stated:

> Domestically, this service will help meet the demand for a seamless, nationwide and eventually global communications system that is available to all and that can offer a wide range of voice and data communication services. In addition to enhancing the competitive market for mobile telecommunication services in areas served by terrestrial mobile services, this new mobile satellite service will offer Americans in rural areas that are not otherwise linked to the communications infrastructure immediate access to a feature-rich communications network. Moreover, Big LEO systems can extend these benefits throughout the world, and can provide those countries that have not been able to develop a nationwide communication service an "instant" global and national telecommunication infrastructure. This network can be used to provide both basic and emergency communications to their entire populations. Big LEO

30/ See Address of Vice President Al Gore to the World Telecommunication Development Conference (Mar. 21, 1994), reprinted in 54 Daily Gov't Rep. (BNA), M-1 (March 22, 1994).

systems may prove to be a critical component in the development of the global information highway.[31/]

Indeed, these benefits underlay the Commission's decision to impose a global coverage requirement on Big LEOs in that proceeding: "In view of our interest in furthering the creation of the global information infrastructure, we proposed to require each MSS Above 1 GHz applicant to demonstrate that its proposed system is capable of providing mobile satellite service to all areas of the world . . ."[32/]

Global systems will further economic and social development internationally. Such systems can bring communications services to those who, whether because of inadequate infrastructure or geographic isolation, currently do not have access to them. This increased access in turn will expand the availability of business opportunities, education, medical care, and a host of other vitally important services.

The benefits to be achieved by global systems include expanding opportunities and resources for U.S. business. As has been documented time and again by Motorola and others, one of the most significant impediments to U.S. investment abroad is the lack of adequate telecommunications infrastructure.[33/] Global systems will address this problem for U.S. companies; they will also significantly reduce the transaction costs of conducting business abroad, and will expand markets for U.S. goods and services.

In short, systems that can provide global coverage will be an essential engine driving economic progress both within the U.S. and abroad for decades to

31/ Big LEO MSS Licensing Order, 9 FCC Rcd at 5940.

32/ Big LEO MSS Licensing Order, 9 FCC Rcd at 5947.

33/ See Comments of Motorola, In the Matter of Amendment of the Commission's Rules to Establish Rules and Policies Pertaining to a Mobile Satellite Service in the 1610-1626.5/2483.5-2500 MHz Frequency Bands, CC Docket No. 92-166 (May 5, 1994) (citing recent articles regarding inadequate infrastructure as an impediment to foreign investment).

come. Developing policies that foster such systems should thus be a Commission priority.

2. The Commission Should Adopt Stringent Financial Standards

The Commission should adopt stringent financial qualification requirements for Ka-band FSS systems. The cost of constructing such systems will be high, necessitating a comparatively stringent standard that would exclude poorly financed applicants. The standard that the Commission has hitherto successfully applied to domestic FSS applications, see 47 C.F.R. § 25.140, is an appropriate standard and should be adopted.[34/] This standard requires applicants to demonstrate their current financial ability to meet the estimated costs of construction, launch and first-year operation of the system by a showing of adequate internal or external financing for such costs.

[34/] The Commission has recently proposed application of the domestic FSS standard to international FSS applicants as well. See In the Matter of Amendment to the Commission's Regulatory Policies Governing Domestic Fixed Satellites and Separate Policies Governing Domestic Fixed Satellites and Separate International Satellite Systems, IB Docket No. 95-41 at ¶ 29 (Released April 25, 1995).

III. CONCLUSION

For the foregoing reasons, the Commission should adopt the rules proposed in the NPRM with the modifications and additions recommended herein.

Respectfully Submitted,

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APPENDIX 1

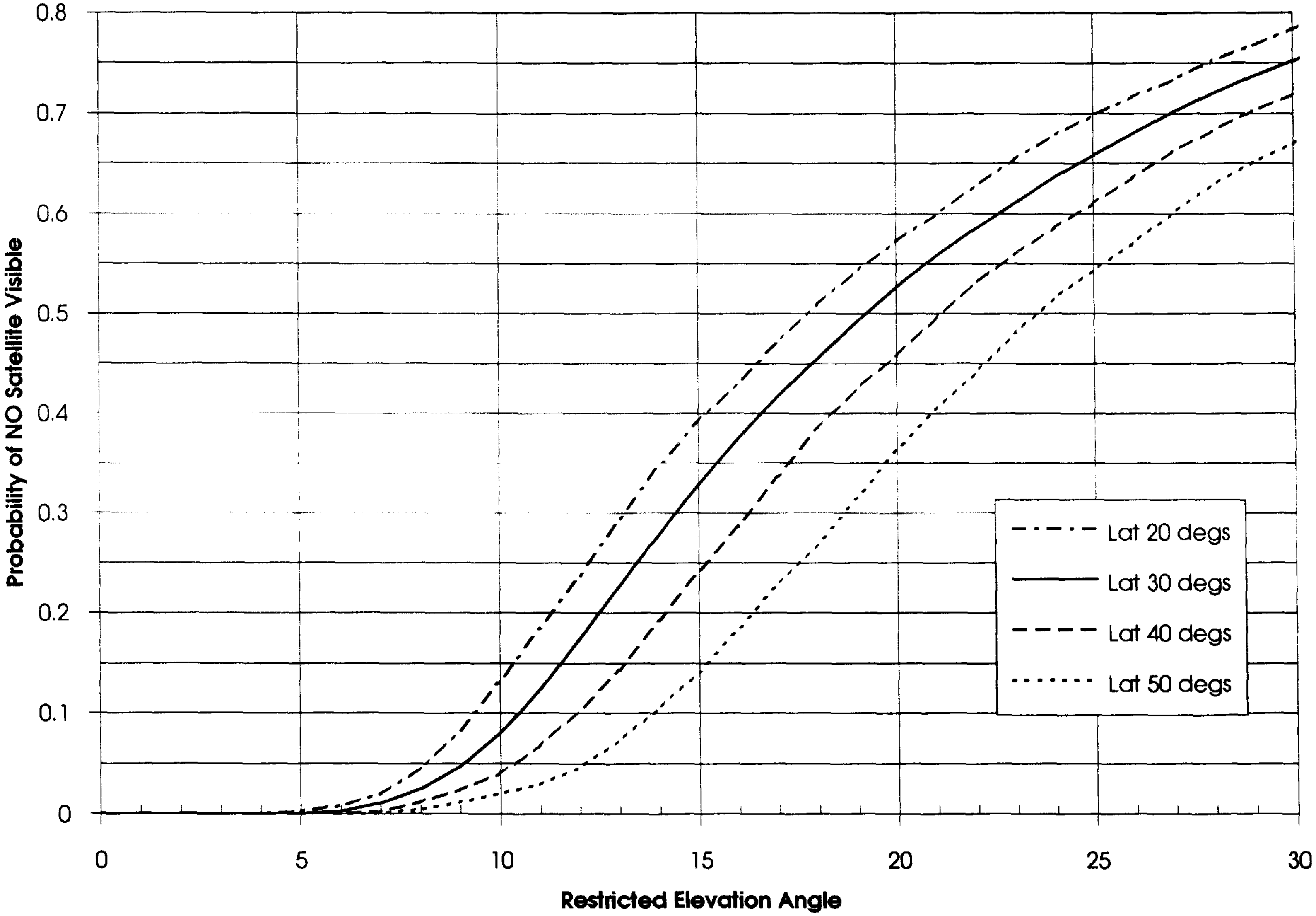
AN INCREASE IN ELEVATION ANGLE FOR THE IRIDIUM® SYSTEM TO 7° OR 8° WOULD COMPROMISE THE LINK ACQUISITION PROCESS AND WOULD NOT REDUCE THE POTENTIAL FOR INTERFERENCE FROM LMDS SUBSCRIBER LINKS

1. A 5° Elevation Angle Is Necessary to Maintain Continuous Communications with the Space Segment.

The MSS feeder link stations must maintain continuous communications with the space segment as the individual space stations pass overhead. Before a satellite falls below an acceptable elevation angle, a link must be completed with another space vehicle so that user voice and data traffic can be continuously transmitted and received. Hence, during the transition period, two satellites must be above the horizon in elevation.

When a new link is established, a link acquisition process must be completed. The process of acquiring an IRIDIUM® downlink is basically the same as that used by many other satellite systems using orbits that are not geostationary. This acquisition process involves searching for the right pointing angle to the satellite, detecting the signal, and then electronically establishing tracking of the carrier frequency, the symbol clock, and frame timing. Simulations of the satellite constellation that include adequate time for the acquisition process (approximately 45 seconds) indicate that low elevation tracking is necessary to maintain continuous communications with the space segment. This holds true for all latitudes below 50 degrees (as shown in Figure 1), a plot of the probability of space vehicle visibility versus restricted elevation angle, from simulation results.

Figure 1
Satellite Visibility Cumulative Distribution Function



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2. An Increase of the Elevation Angle to 7° or 8° Would Not Reduce the Interference Potential from LMDS Subscriber Links.

Even though the MSS feeder links use narrow spot beam antennas (2.4 degree beamwidth at 30 GHz) at low elevation angles, the 3 dB contour of the satellite footprint on the Earth's surface is large. The large footprint area exposes the space vehicle to illumination by a large number of LMDS transmitters. Figures 2 through 4 depict the satellite footprint at 5, 8, and 10 degrees elevation angles relative to the IRIDIUM® Gateway site. The Gateway is at the 0 kilometer axis crossovers, and all distances are in kilometers relative to the Gateway location. The angle at which an LMDS transmitter will intercept the main beam of the space vehicle varies throughout the footprint area. Elevation angle intercepts are constant on the horizontal axis, but increase and decrease on the vertical axis. Positive distances (upward) from the Gateway result in decreasing elevation intercept angles until the edge of the Earth is encountered.

The broad area at the top of the 3 dB contour is where low elevation angle intercepts are encountered. As the figures illustrate, the area where low elevation angle intercepts occur (at the top of the footprint) is reduced with a higher Gateway elevation angle, but only slightly (approximately 10-15%). However, while there is a minor drop in low elevation angle intercept area, the total footprint area also increases slightly (also approximately 10-15%) The net effect is that increasing the minimum elevation angle (for operation of MSS feeder link stations) from 5 degrees to 7 or 8 degrees does not result in a reduction in interference potential.

Figure 2
Satellite footprint at 5 degree elevation angle

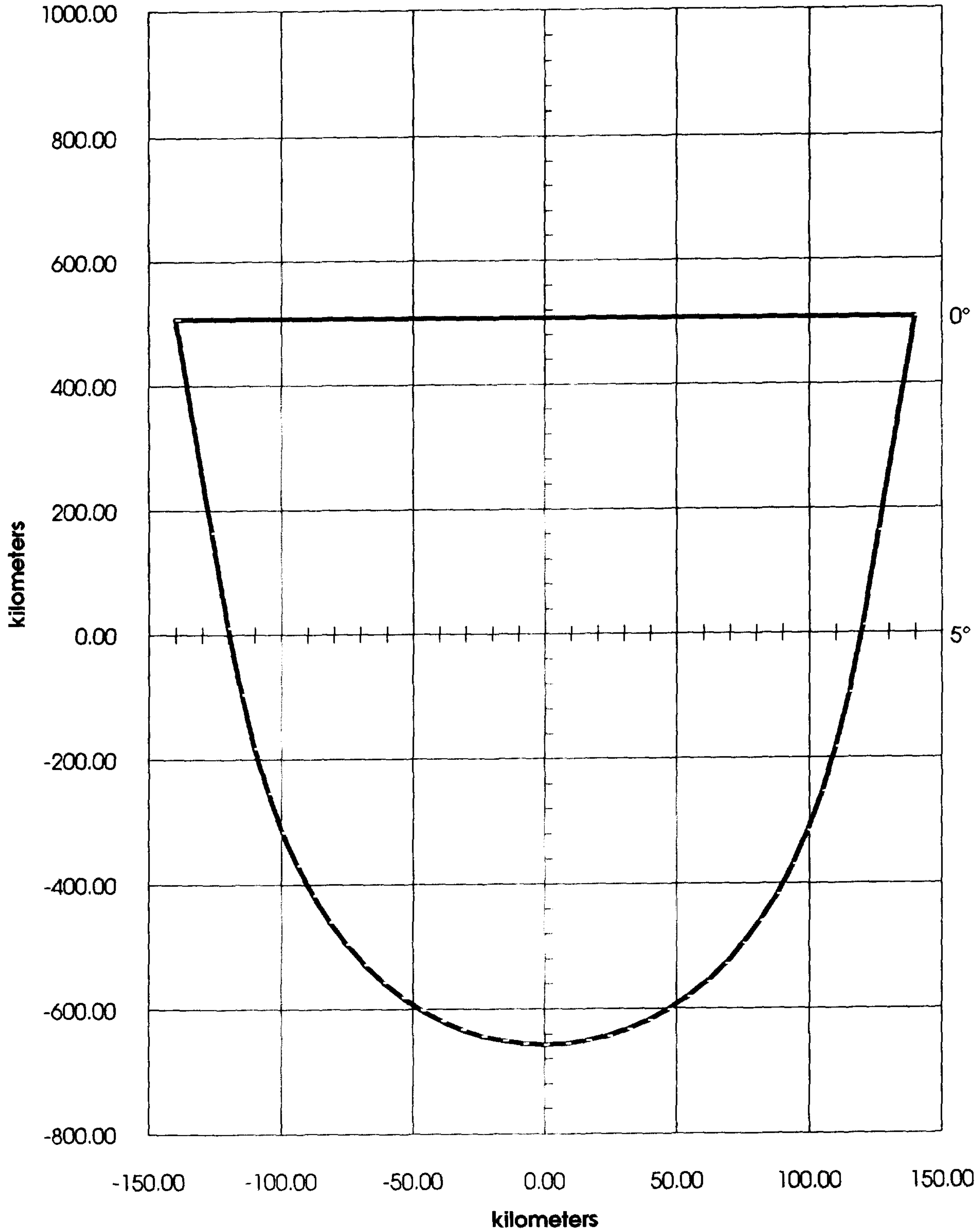

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Figure 3
Satellite footprint at 8 degree elevation angle

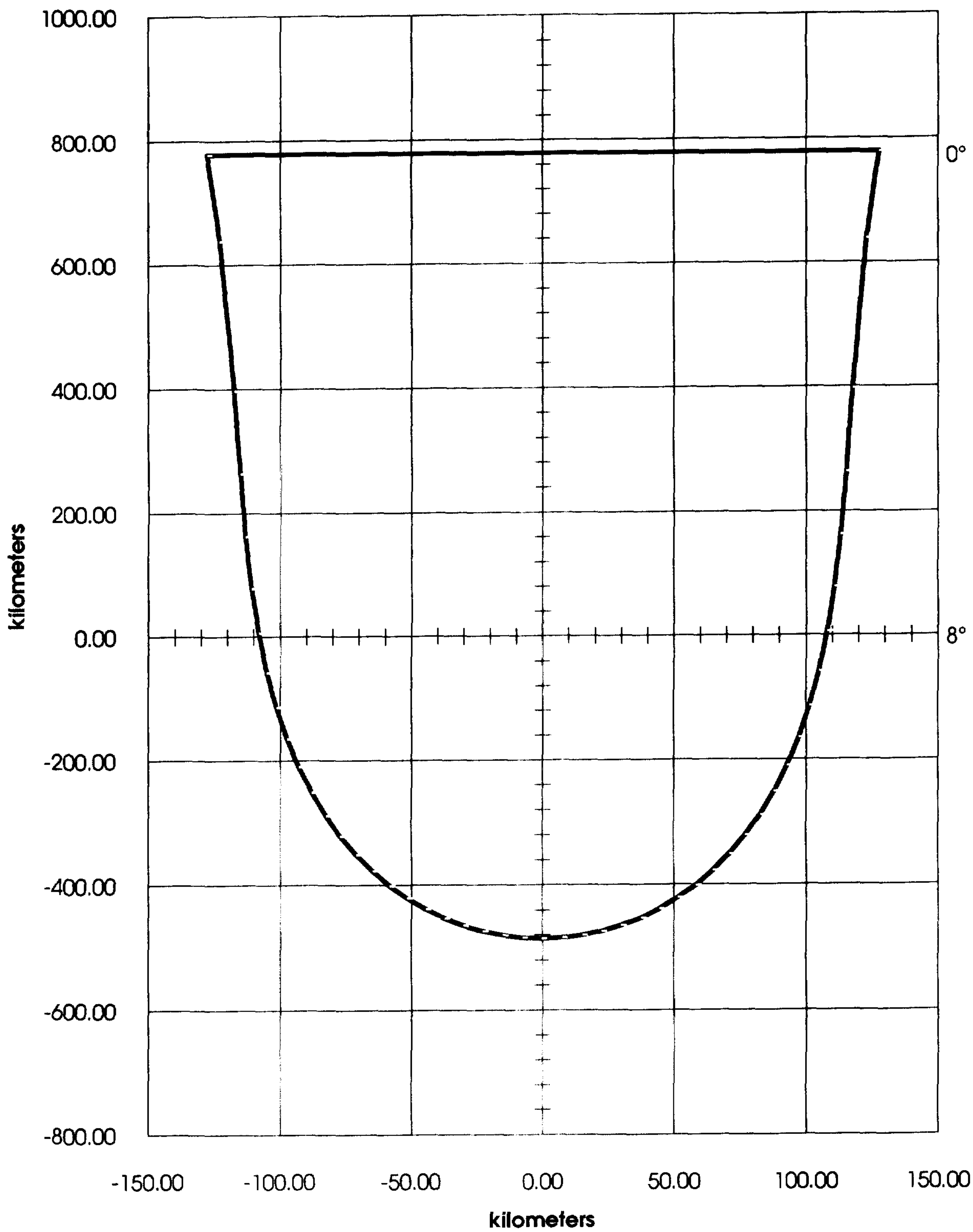

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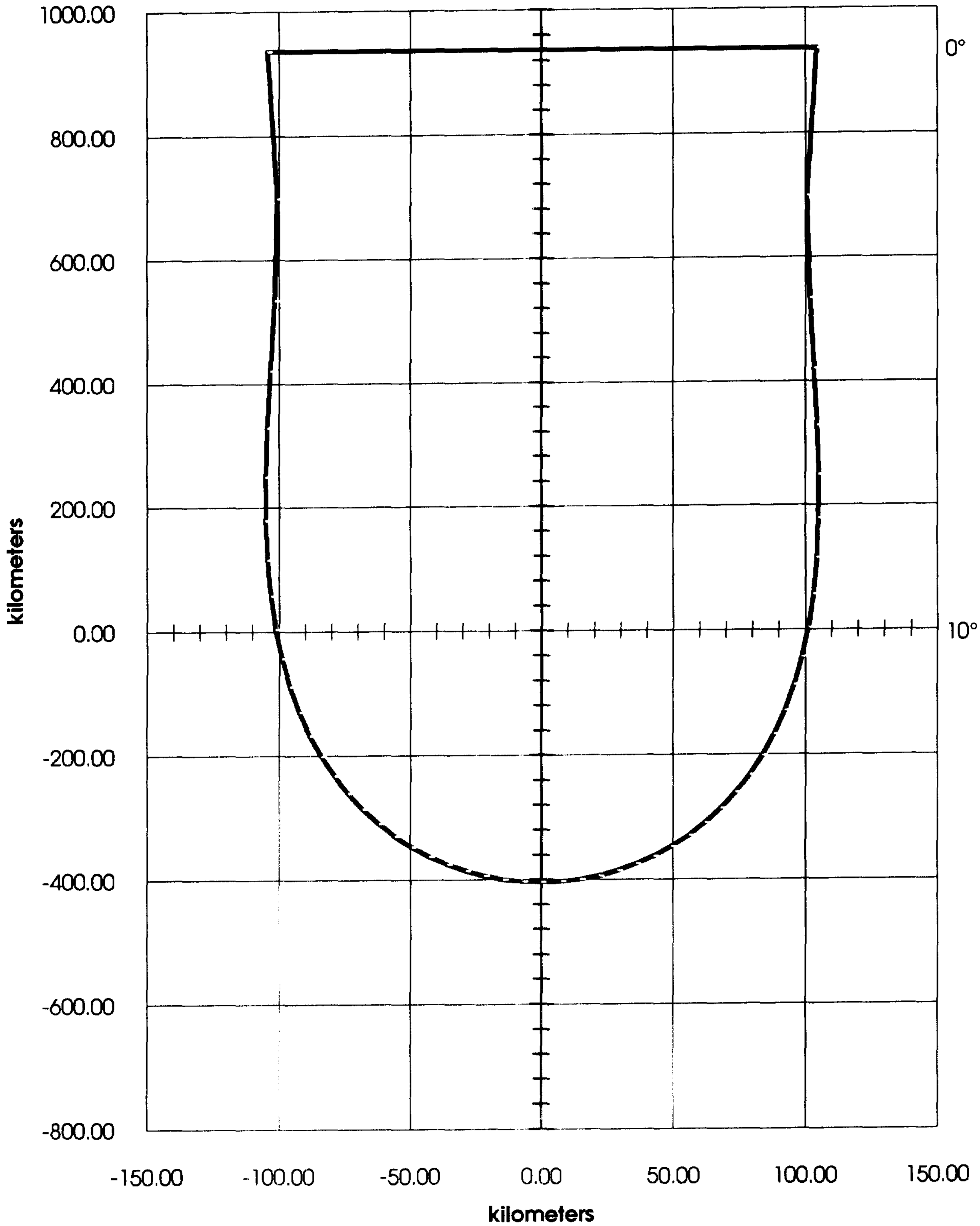
Figure 4
Satellite footprint at 10 degree elevation angle



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APPENDIX 2

Possible Coordination Strategies Between Non-GSO Feeder Links and GSO Networks

Introduction

If spectrum is to be shared between MSS feeder links and geostationary FSS systems, Motorola agrees that co-frequency co-geographic sharing between the two is not possible based on simulations presented by Hughes Aircraft Co to IWG4(#15A) of IAC using the proposed characteristics of the Spaceway and Iridium systems, coordination studies between Iridium and Japanese GSOs. The results of those studies are confirmed by recent simulations of interference between Spaceway and Iridium as detailed in the Annex to this Appendix. Sharing is only possible with some form of mitigation.

Short Term Interference Budgets

The Annex to this Appendix studies through computer simulation the mutual interference between GSO systems and the IRIDIUM feeder links. In order to evaluate the results of a statistical simulation of short term interference and the benefits of mitigation, it is necessary to have a budgeted allocation for this interference from another network. Motorola had offered the following allocation in IWG4 to short term interference with rationale based on IRIDIUMs system availability and KaBand propagation statistics:

I ≤ .79Nt for .01% of time on an annual basis cumulative considering both the up and down link and from all interfering systems.

It is possible and even likely that outages from GSO interference events would occur at different times in the up and down link of the NonGSO network. Therefore, it is necessary to compute the two separately and add them together. It is also assumed there are no other sources of short term interference to contribute to budget such as FS interference into down link earth terminals. It is also difficult to allocate a **single entry** budget from one GSO network. At KaBand, most GSO systems use relatively narrow spot beams on the spacecraft, and can therefore, have a number of co-frequency earth terminals serving one position on the arc. Each of those could contribute to the NonGSO interference along with additional satellites positioned every few degrees. Depending on the latitude there could be 30 or 40 space stations contributing interference every 2 degrees of the arc.

The GSO proponents at KaBand have failed to provide a budget for short term interference based on the particular systems' service objectives and link margins. Intelsat proposed a interference statistical mask (Table 8A Part C, CPM-95 Report) based on a hypothetical large trunking type of service (99.9% availability), using site diversity and large link margins to meet this availability goal.

Notwithstanding these uncertainties, Annex Table 5 clearly shows excessive interference into the Iridium system for about **0.31%** of a year when co-located with a GSO VSAT earth terminal and its' 66 cm antenna (0.01% on down link and .3% in the uplink). It also shows the most severe problem is the up link from a GSO earth terminal into a low orbiting spacecraft due to the differential path losses. The interference is less for a larger antenna such as Spaceway's 2 meter antenna as can be seen in Table 10. Here the combined interference is **0.088%** still well over the total budget of 0.01% from all networks.

Coordination with Geographic Separation of Earth Terminals

Very Small Aperture Terminals ("VSATs"), represent a particularly difficult problem in coordination. A Canadian input to the CPM on sharing between Odyssey and a Canadian VSAT GSO network concluded "...where small fixed (approximately 0.2m diameter antennas) and mobile earth stations are used by the GSO networks, sharing between such networks and non-GSO/MSS feeder links would place severe constraints on the GSO networks for protection of the non-GSO/MSS feeder links." (CPM final report section 3.18 Part C) The Canadian analysis indicated that 1000 km of geographic separation between co-frequency earth terminals was required.

Obviously, some type of earth terminal restrictions will be required for the GSO such as type, number and location in order to complete a successful coordination. VSATs do not lend themselves to these restrictions and obviously should not be allocated to the band segment to be shared with MSS feeder links. The interference into Spaceway's up link appears to be negligible because of the extra space loss to the GSO arc but it is unknown if the interference levels into a GSO as calculated in the Annex are a problem on the down link. Geographic separation was examined in the simulations of the Annex. Table 5 indicates that even with separations of up to 3 degrees (180 NM) the down link interference changes very little because of the finite footprint of the GSO spot beam. The up link is more sensitive to geographic separation and 180 NM drops the up link interference statistics from 0.30% to 0.01% (Table 5) for a total of **0.02%** up and down link which still exceeds Iridium's proposed accumulative criteria. Clearly co-frequency sharing with both networks is not feasible if the GSO employs VSATs.

If larger GSO earth terminals are employed, there is a better opportunity for geographic separation reducing the interference to permissible levels. Table 10 shows that with a 180 NM separation from a 2 meter Spaceway station, the interference from a single GSO earth station is reduced to **0.006%** -- just below total budget.

Effect of power control on coordination

It is crucial to examine the power control strategies of each system as large link margins are required to compensate for the severe rain attenuation losses at KaBand. Iridium dynamically adjusts the up and down links powers to compensate for range and atmospheric attenuation. This complies with Sec 25.204(d) that requires earth stations above 10 GHz to transmit only the power necessary to achieve "desired signal quality". The down link pfd is limited by 25.208(c) which sets levels to protect Fixed Service stations.

Spaceway complies with both requirements but does not dynamically control its down link. Rather, it simply maintains a running margin of about 6.5 dB. It should be noted that the FCC's up link EIRP restriction is not reflected in the international regulations. National GSO systems in Japan and Italy employ a different power control strategy. Japan operates continually with nearly 30 dB link margins on both the up and down links. Italsat dynamically adjusts the gain of its transponder. Thus, it essentially adapts its down link to the atmospherics, but it does not adapt its uplink EIRP which is comparable in level to Japanese GSOs.

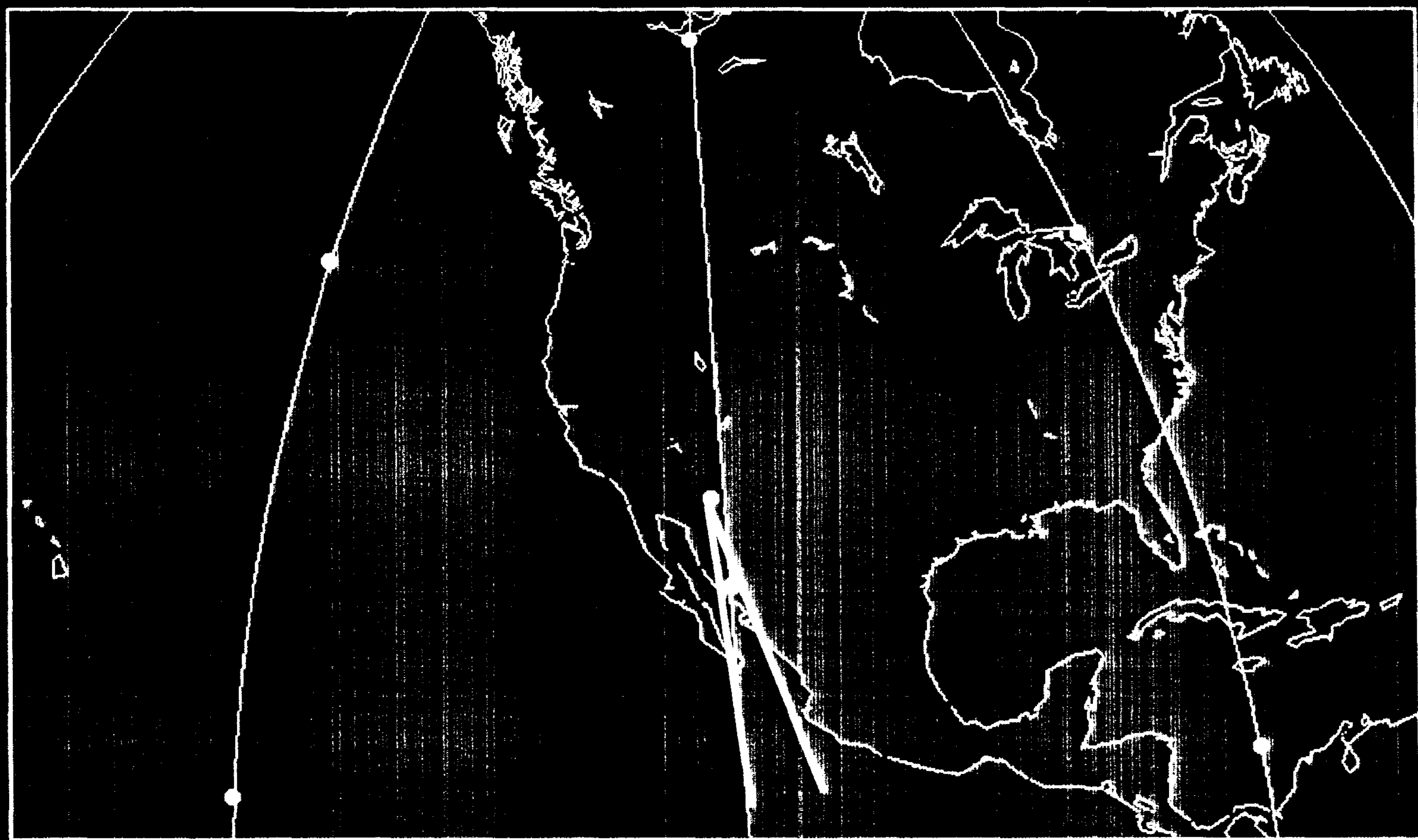
These foreign systems therefore create about 10 times as much interference to an Iridium down link and about twice as much to the uplink compared to the Spaceway system, even though large GSO earth station antennas are involved. Table 14 of the Annex shows that for the Japanese system COMETS, the combined interference is **0.78%**. On the other hand, the GSO systems are quite robust to external interference with these large running margins. Coordination for a Non-GSO in these two countries was therefore quite difficult and frequency/orbit avoidance was the best solution in Japan as there are only 2 co-frequency GSO spacecraft on an up link portion (75%) of the band and another GSO satellite covers the remaining 25%. Italy has only one GSO satellite for KaBand. This satellite assigns its up and paired down link frequency to widely separated spot beams which facilitates coordination.

In the US, it might be possible to use power control as a mitigation technique between a few terminals and a few orbital slots particularly if in combination with geographic separation. Power control might require temporarily exceeding the limit of §25.204(d). That rule seems to leave this option open by providing for the possibility of amendment by coordination agreement.

Satellite diversity as a mitigation factor

It is suggested that it is "conceptually " possible to switch to an alternative Non-GSO satellite to avoid an in line event if inter satellite links are employed. The Iridium system employs inter satellite links but visibility statistics of the 66 satellite system at mid or lower latitudes preclude this possibility. Figure 1 shows that, if an in line event occurred between a NonGSO earth terminal in Chandler AZ and GSOs at about 100 deg longitude, there would be no other Iridium satellite in view to accept traffic from the gateway. As can be seen from the figure, there is no satellite visible above an elevation angle of 10°. Clearly, if this technique would be necessary, a major expensive upgrade of an IRIDIUM type constellation would be required.

Figure 1 In-Line Event Geometry



Dots are satellites
Vertical solid lines are satellite tracks
Center dot is Phoenix Arizona Gateway

Outer Circle = 10 deg. el. angle
(min. comm. angle)
Middle Circle = 44 deg.
Inner Circle = 56 deg.

Interference occurs between 44 and 56 deg. elev.. and 154 and 167 deg. azimuth for -99 and -101 GEO satellite locations.

Annex:
Geometrical Analysis of Space-borne Communication systems

This report outlines a geometrical analysis between two space-borne communication systems. The interpretation of this analysis to reflect on the impact on the systems interference level requires additional analysis (Attachment I). An example of the IRIDIUM® system sharing with SPACEWAY and COMETS is shown in Attachment II.

Simulation Description

The output result is the percent of time that the range gain product for all interference paths is above a certain level. The interference paths are:

	Space Vehicle (Constellation 1)	Ground Station (Constellation 1)
Space Vehicle (Constellation 2)	None	Uplink -> Uplink Downlink -> Downlink
Ground Station (Constellation 2)	Downlink -> Downlink Uplink -> Uplink	None

This range gain product for space vehicle 1 downlink into ground station 2 downlink is computed as (Figure 1),

$$\frac{G_t(\varphi_1)G_r(\varphi_2)}{4\pi R^2} \tag{1}$$

where

$G_t(\varphi_1)$ The Transmit Gain of the space vehicle of constellation 1 in the direction of the ground station of constellation 2.

$G_r(\varphi_2)$ The Receive Gain of the ground station of constellation 2 in the direction of the space vehicle of constellation 1.

R Range between the space vehicle of constellation 1 and the ground station of constellation 2.

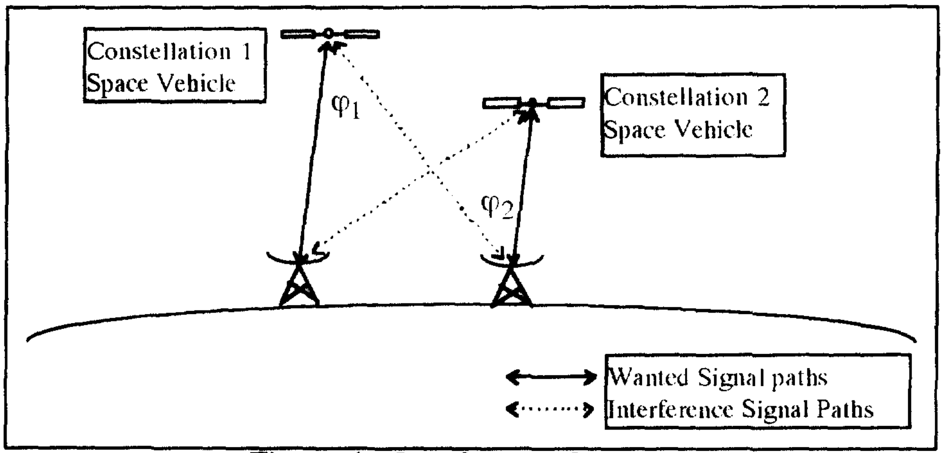


Figure 1. Interference Geometry

Simulation Assumptions

Orbit model

The orbit model assumes spherical orbit above a spherical earth.

Antenna Parameters

The antenna parameters are generated with the Appendix 29 Model (Annex III)

$G(\varphi)$	- Antenna Gain (dBi)
φ	- Off-axis angle of the antenna, in degrees
D	- Antenna diameter
λ	- Wavelength (same units as D)
$G_{\max}$	- Maximum gain of Antenna (dBi)
$G_1 = 2 + 15 \log \frac{D}{\lambda}$	- Gain of the first sidelobe (dBi)
$\varphi_m = \frac{20\lambda}{D}\sqrt{G_{\max} - G_1}$	- Start of first sidelobe (degrees)
$\varphi_r = 15.85\left(\frac{D}{\lambda}\right)^{-0.6}$	- End of first sidelobe (degrees)
$\frac{D}{\lambda} \approx 10^{(G_{\max} - 7.7)/20}$	- Approximation of antenna diameter

where for values of $\frac{D}{\lambda} \geq 100$

$$G(\varphi) = \begin{cases} G_{\max} - 0.0025\left(\frac{D}{\lambda}\varphi\right)^2 & 0 < \varphi < \varphi_m \\ G_1 & \varphi_m \le \varphi < \varphi_r \\ 32 - 25\log\varphi & \varphi_r \le \varphi < 48^\circ \\ -10 & 48^\circ \le \varphi < 180^\circ \end{cases} \tag{2}$$

and for values of $\frac{D}{\lambda} < 100$

$$G(\varphi) = \begin{cases} G_{\max} - 0.0025\left(\frac{D}{\lambda}\varphi\right)^2 & 0 < \varphi < \varphi_m \\ G_1 & \varphi_m \le \varphi < 100\frac{\lambda}{D} \\ 52 - 10\log\frac{D}{\lambda} - 25\log\varphi & 100\frac{\lambda}{D} \le \varphi < 48^\circ \\ 10 - 10\log\frac{D}{\lambda} & 48^\circ \le \varphi < 180^\circ \end{cases} \tag{3}$$

Operational Assumptions

It is assumed that the ground station, associated with a constellation, ideally tracks the corresponding satellite once it has a communication link established. When this satellite is beyond the minimum elevation angle it is assumed that the next satellite can be acquired before the next simulation time step. The algorithm to select the next satellite is based on the vector from the ground station to the potential satellite, $(\vec{r})$, and the unit vector in the direction of the satellites velocity, $(\vec{v})$. The selection criteria is

$$\min_{\substack{\text{all satellites above} \\ \text{minimum elevation}}} \vec{r} \cdot \vec{v} \tag{4}$$

This selection procedure is shown in Figure 2. The top view representation shows the satellite, denoted by $\vec{v}_1$, traveling towards ground station therefore the dot product is negative and it is selected over the other satellite.

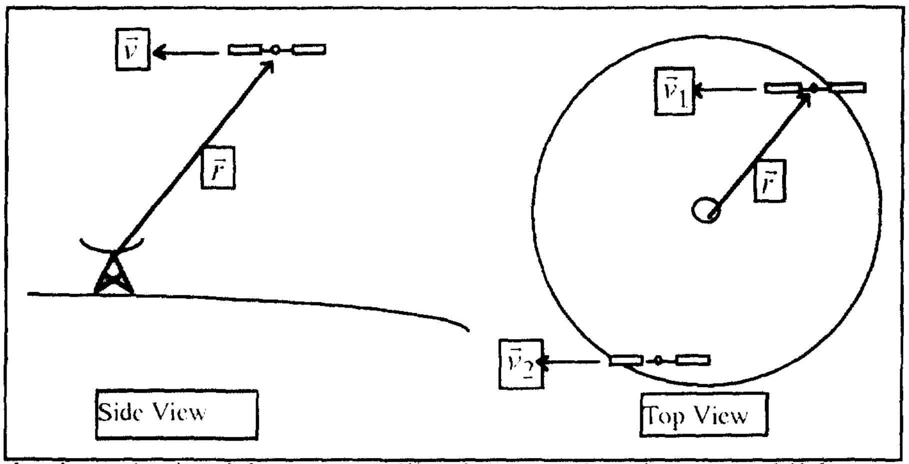


Figure 2. Selection criteria of the next satellite the ground station to establish a communication link.

Input Data

The required input parameters for each of the two communication systems are:

Orbit parameters:

- Number of Satellites
- Number of Planes
    - Orbit altitude
    - Inclination of plane
    - Right ascension of the ascending node
    - Anomaly of first satellite in each plane (all other satellites in the plane are equally spaced)

Antenna parameters:

- Space vehicle
    - Maximum Transmit Gain (dBi)
    - Maximum Receive Gain (dBi)
- Ground Station
    - Maximum Transmit Gain (dBi)
    - Maximum Receive Gain (dBi)
    - Location
        - North Latitude
        - West Longitude

Operational parameters:

- Minimum elevation angle for communication
- Simulation time start
- Simulation time end
- Simulation time increment
- Desired link to mitigate and the level below the maximum range gain product at which the mitigation is to take place (Optional).

Attachment I: Conversion from range compensate gain product to I_0 / N_0 .

To compute the interference to noise ratio I_0 / N_0 the following equation can be used

$$\frac{I_0}{N_0} = \frac{P_t}{BW_{tx}} G_t(\varphi_1) G_r(\varphi_2) \left(\frac{\lambda}{4\pi R}\right)^2 \frac{1}{kT} \tag{5}$$

$$= \frac{P_t}{BW_{tx}} \frac{\lambda^2}{4\pi} \frac{1}{kT} \frac{G_t(\varphi_1) G_r(\varphi_2)}{4\pi R^2}$$

where

P_t - Transmit power (Watts)

BW_{tx} - Transmit bandwidth (Hz)

$G_t(\varphi_1)$ - Transmit gain (relative intensity)

$G_r(\varphi_2)$ - Receiver gain (relative intensity)

λ - Wavelength of transmitter (m)

R - Range (m)

k - Boltzsman constant (1.38×10^{-23} w-s/deg K)

T - Noise temperature (deg Kelvin)

Therefore to compute I_0 / N_0 the range gain product must be multiplied by $\frac{P_t}{BW_{tx}} \frac{\lambda^2}{4\pi} \frac{1}{kT}$. This conversion assumes that no power control is used by the transmitting system.